AirMOSS: An Airborne P-band SAR to Measure Root Zone Soil Moisture

Elaine Chapin[1], Alexandra Chau[1], Jacqueline Chen[1], Brandon Heavey[1], Scott Hensley[1], Yunling Lou[1], Richard Machuzak[1], Mahta Moghaddam[2]

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]University of Southern California

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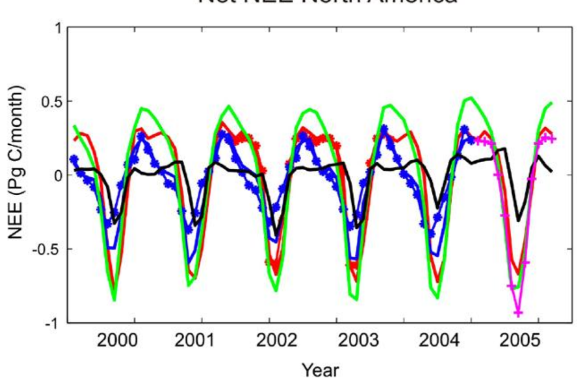
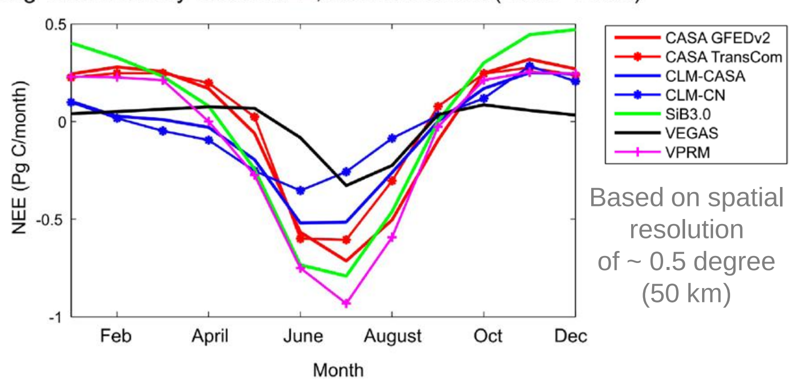
AirMOSS Science Objectives

AirMOSS, a 5-year project funded by NASA's Earth Venture Program, will provide a new Net Ecosystem Exchange estimate for North America with reduced uncertainty by:

- Providing *100 m resolution observations of Root Zone Soil Moisture (RZSM)* over regions representative of the major North American biomes
- Quantifying the impact of RZSM on the estimation of regional carbon fluxes
- Upscaling the reduced-uncertainty estimates of regional carbon fluxes to the continental scale of North America

Net ecosystem exchange, commonly known as NEE, is a measure of how much carbon is entering and leaving the ecosystem. While at first glance this may seem simple, carbon is a very common element and is found in all types of life. One of the most common indications of carbon change in net ecosystem exchange is CO_2 or carbon dioxide, which moves between vegetation, soil, and atmosphere, and is strongly influenced by root zone soil moisture.



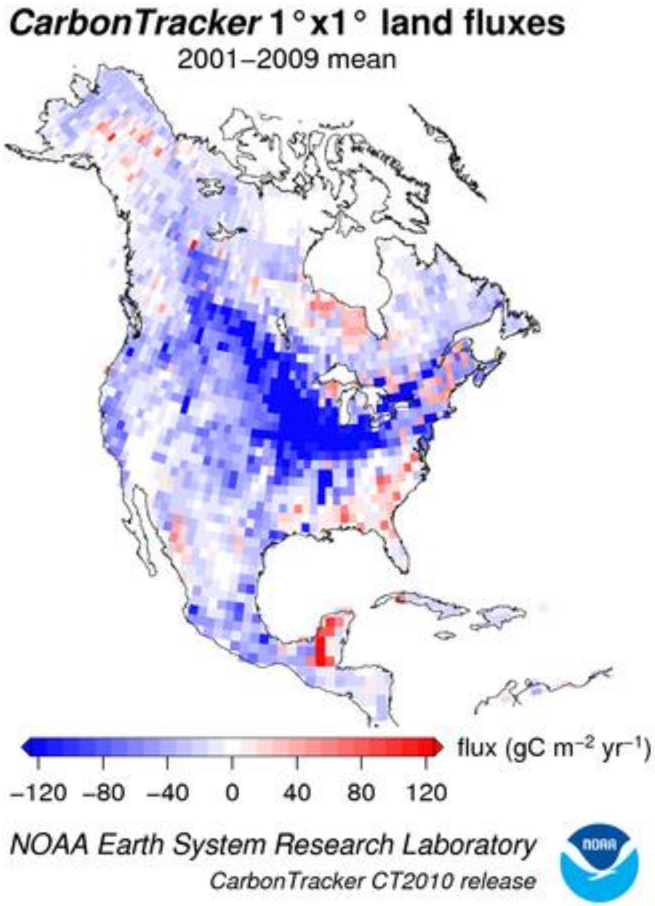


Based on spatial resolution of ~ 0.5 degree (50 km)

Current NEE models exhibit wide variability, which may be reduced by having better estimates of Root Zone Soil Moisture.

Why is Root Zone Soil Moisture (RZSM) Important?

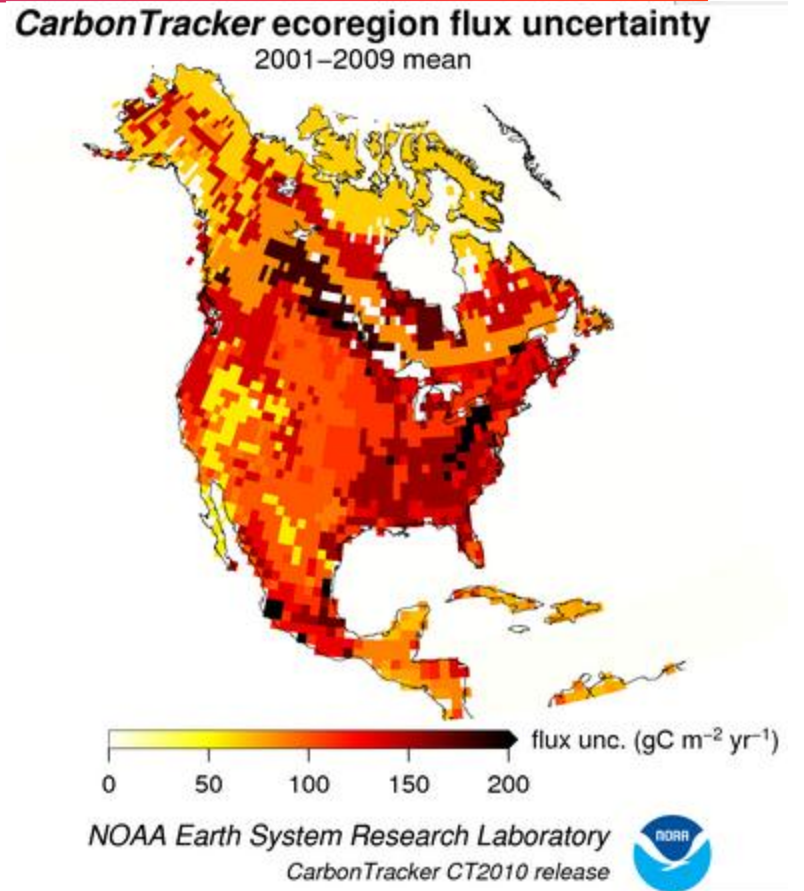
- Understanding how ecosystems exchange carbon with the atmosphere is a driving scientific and societal question.
- How much carbon plants sequester, absorb from the atmosphere, is affected by how much water is available to their roots.
- Knowledge of RZSM is currently derived from localized, point-scale measurements at flux tower sites.
- Lack of current knowledge about RZSM and its spatial distribution is believed to contribute 60-80 percent of the uncertainty about how much the ecosystem exchanges carbon with the atmosphere (net carbon flux).



Root Zone Soil Moisture is an important input for ecosystem modeling, but is poorly understood over large spatial scales

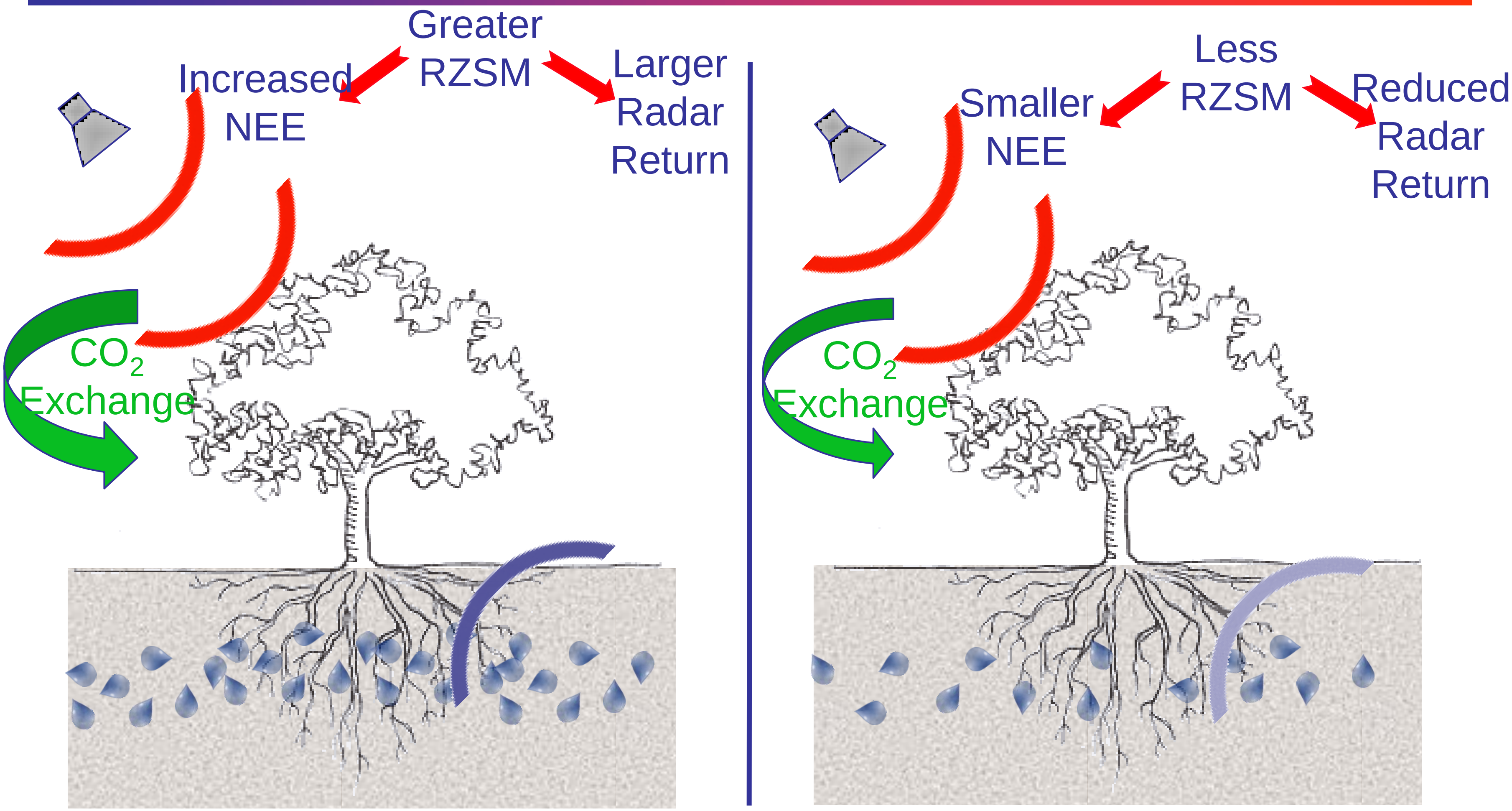
Why is AirMOSS Important?

- AirMOSS will use a P-band radar to penetrate through the vegetation and into the soil where plants' roots are, over >2000 km^2 regions.
- The radar imagery will be converted into estimates of the Root Zone Soil Moisture (RZSM).
- The RZSM estimates will be input into models predicting atmospheric gases. The additional input should improve the accuracy of the model results.
- Comparisons of the model results with and without the RZSM data will be used to quantify the effect of RZSM on atmospheric carbon fluxes.



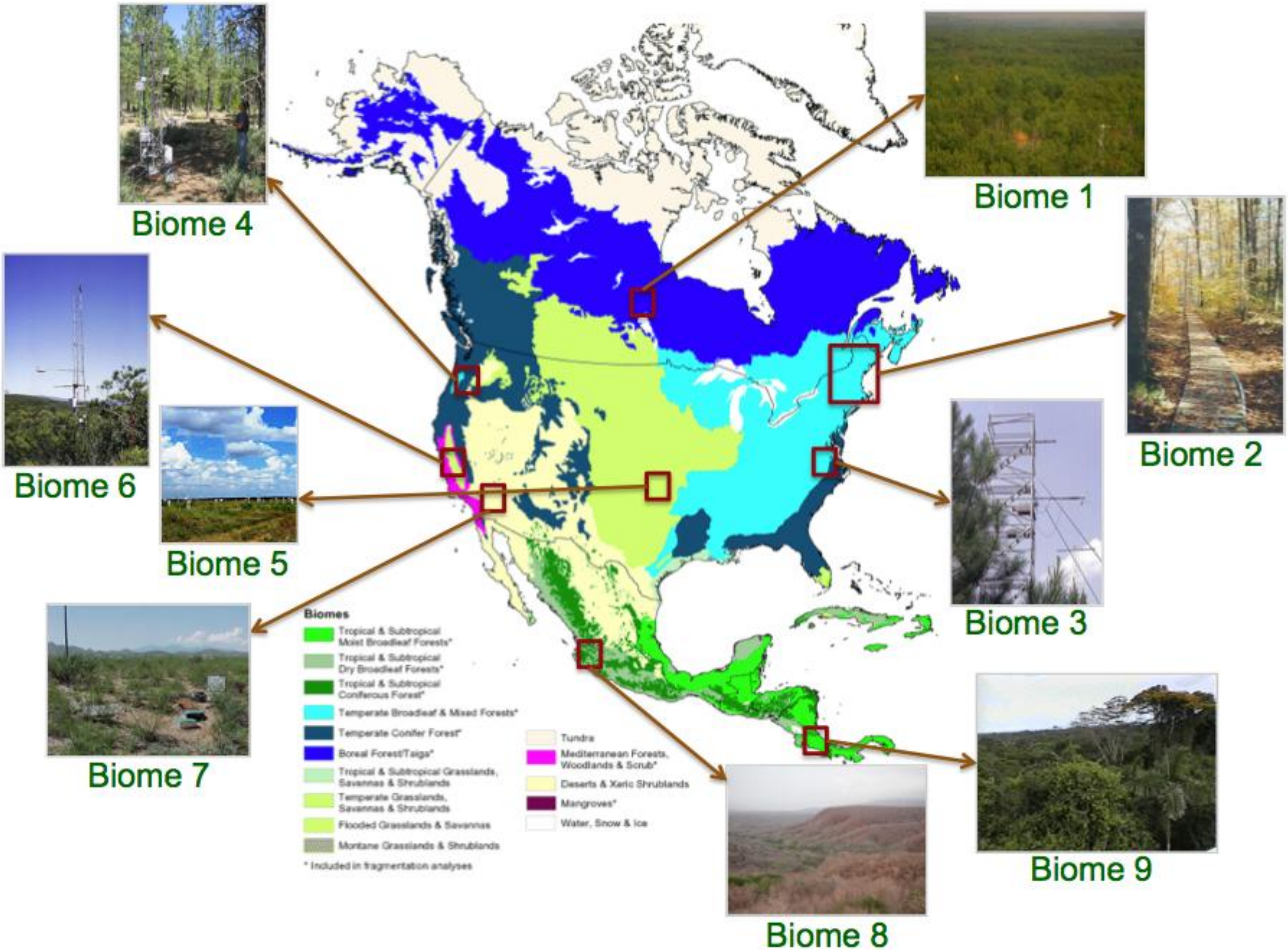
AirMOSS will measure Root Zone Soil Moisture over larger spatial scales than current techniques allow, reducing uncertainty in ecosystem models

Radar, Root Zone Soil Moisture, and NEE



NEE is strongly influenced by Root Zone Soil Moisture, which can be measured via its effect on radar return power

North American Biomes to Cover



1 BERMS, Saskatchewan, Canada
2 Howland & Harvard Forests, ME / MA
3 Duke Forest, NC
4 Metolius, OR
5 SMAP MOISST, Marena, OK
6 Tonzi Ranch, CA
7 Walnut Gulch, AZ
8 Chamela, Mexico
9 La Selva, Costa Rica

Expected Penetration Depth at 430 MHz

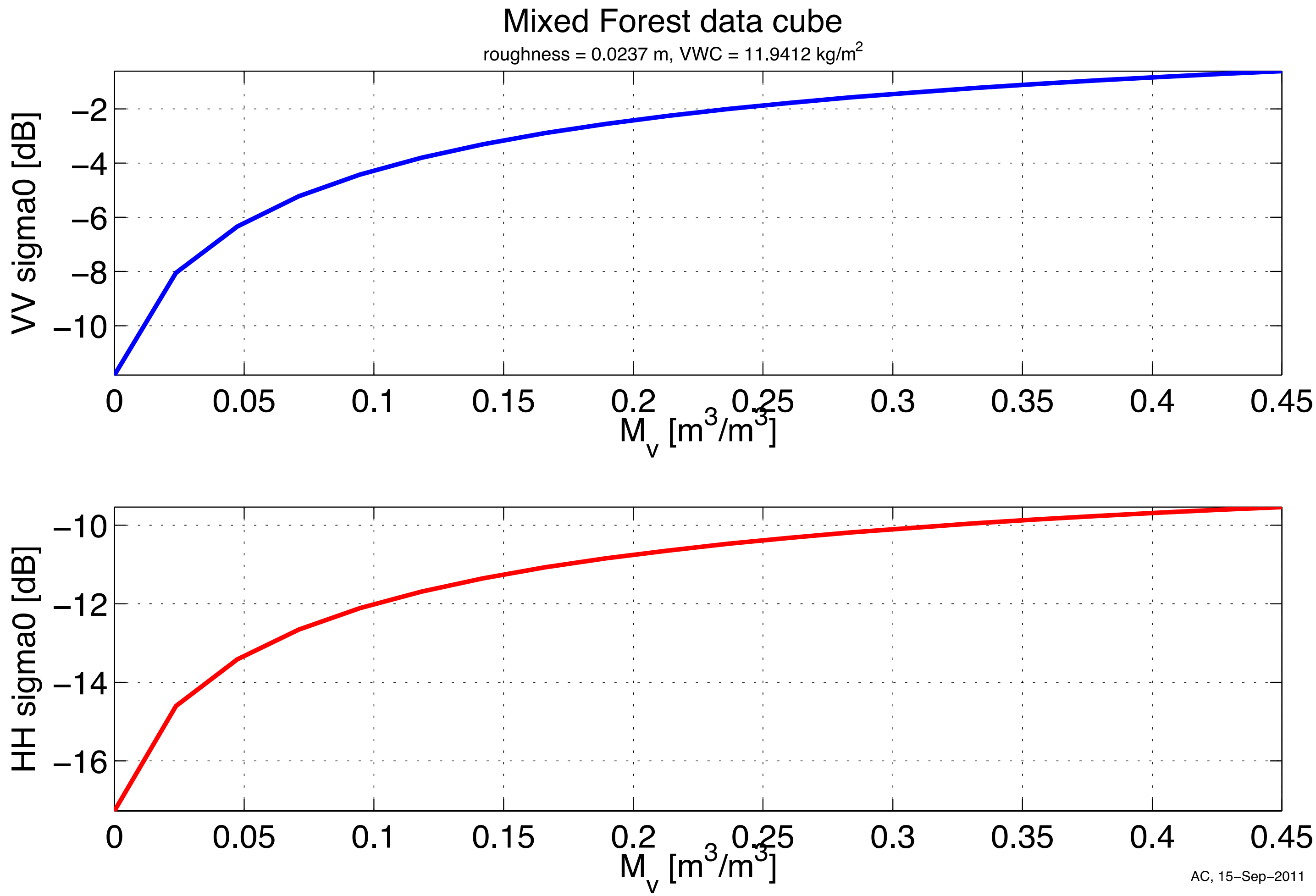
- P-band is suitable for RZSM because it can penetrate tens of centimeters into the ground
- “Expected typical depth of sensing” is estimated based on our current knowledge and assumptions on soil texture, roughness, vegetation cover, and radar system performance characteristics, and may change if these assumptions change. Assumes incidence angle < 45° .

Biome type	Root Zone Depth of Interest (m)	Expected Typical depth of sensing at 430 MHz (m): (dry 0.1 m^3/m^3 / wet 0.3 m^3/m^3)
1. Boreal forest (BERMS)	0.26	1.10 / 0.80
2. Temperate forest (Harvard/Howland)	0.37	0.90 / 0.70
3. Temperate forest/woodland (Duke)	0.37	0.50 / 0.40
4. Forest, intermediate growth (Metolius)	0.26	0.65 / 0.50
5. Agriculture/crops/grassland (ARM/SGP)	0.19	0.25 / 0.20
6. Western Savanna/grassland (Tonzi Ranch)	0.24	0.40 / 0.35
7. Arid/Semi-arid (Walnut Gulch)	0.33	1.80 / 1.40
8. Subtropical Dry Forest (Chamela)	0.29	0.40 / 0.35
9. Tropical (La Selva)	0.33	0.30 / 0.20

From this table to the left, the expected typical depth of sensing at 430 MHz exceeds the root zone depth of interest for all biome types except for Type 9 “Tropical (La Selva)”.

P-band for Soil Moisture Retrieval

- However, backscatter curves saturate with respect to soil moisture
  - Need well calibrated sigma0s for inversion algorithms!
    - *I.e.*, 0.5 dB calibration error to achieve desired 0.05 m^3/m^3 RZSM error



AirMOSS Instrument Heritage


NASA/Dryden G-III

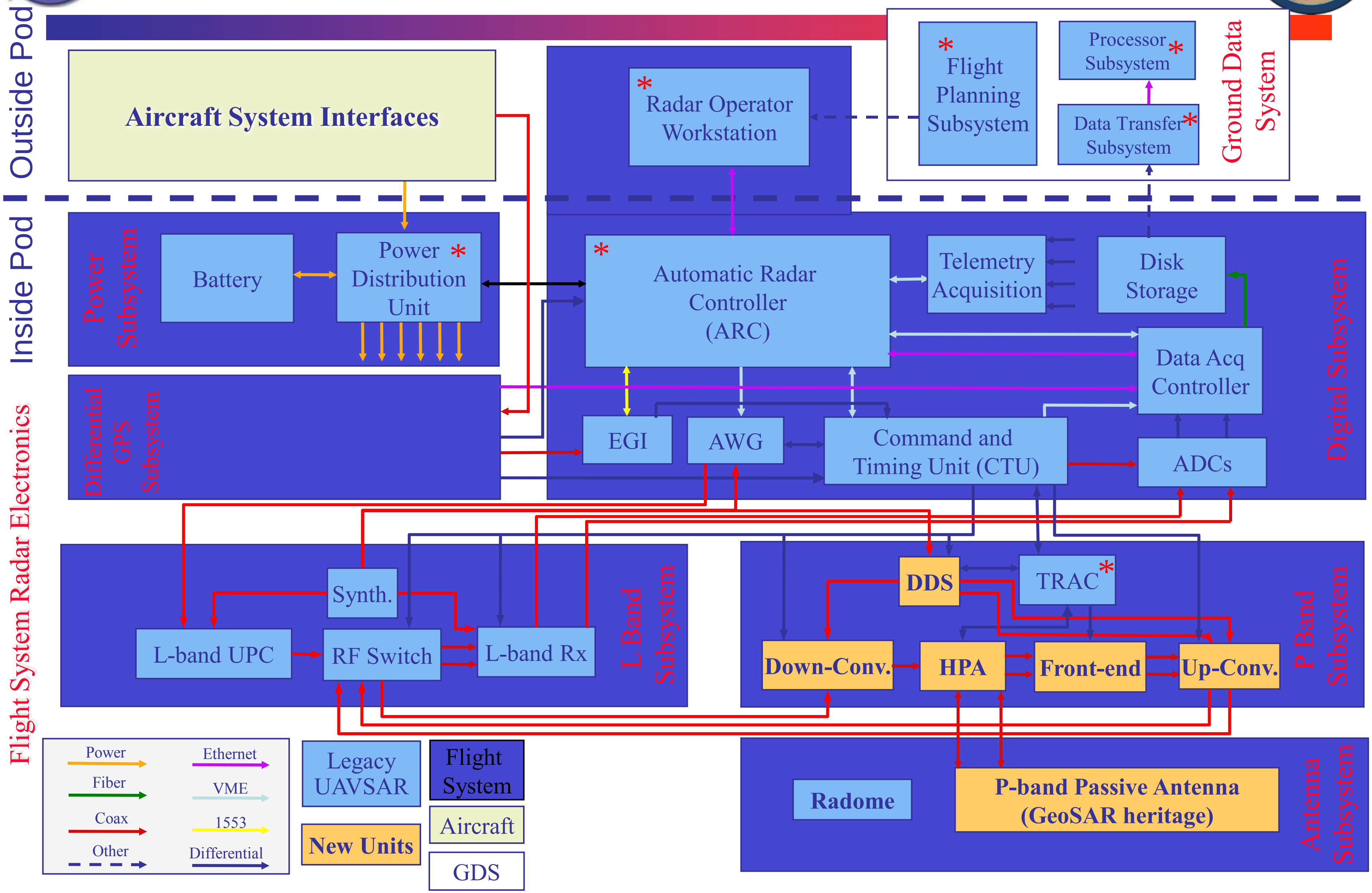

Radar Pod

- AirMOSS instrument is a fully polarimetric, P-band (aka UHF) strip map synthetic aperture radar (SAR)
- AirMOSS hardware is primarily based on UAVSAR heritage, which currently operates in L-band and flies on a NASA/Dryden Gulfstream-III aircraft. Major changes are:
    - Replace L-band active phased array antenna with a P-band patch antenna
    - Add 2.0 kW High Power Amplifier (HPA) to nose cone
    - Add electronics to convert L-band to P-band
    - Fly on NASA/JSC Gulfstream-III aircraft equipped with same Precision Autopilot and instrument interface as NASA/Dryden Gulfstream-III
- First engineering flights to begin June 2012 and science flight campaigns to begin late Summer 2012

AirMOSS Instrument Characteristics

	AirMOSS	UAVSAR
Frequency Band	P-band/UHF	L-band
Frequency (MHz)	280 - 440 MHz	1217.5-1297.5
Nominal Bandwidth (MHz)	20	80
Selectable Bandwidths (MHz)	6, 20, 40, 80	80
Nominal Slant Range Resolution (m)	7	1.8
Azimuth Resolution (m)	0.8	0.8
Nominal Spatial Posting (m)	15	6
Polarization	Quad-pol	Quad-pol
Pulse Length (microseconds)	5-50	5-50
Nominal Altitude	12.5 km (41 kft)	12.5 km (41 kft)
Nominal Platform Velocity (m/s)	221	221
Peak Transmit Power (kW)	2.0	3.1
Maximum Duty Cycle	10%	8%
Look Angle Range	25 – 45 deg	25-65 deg
Nominal Range Swath (km)	7	22
Noise Equivalent Sigma0 (dB)	> -40	>-50

AirMOSS Electronics Block Diagram



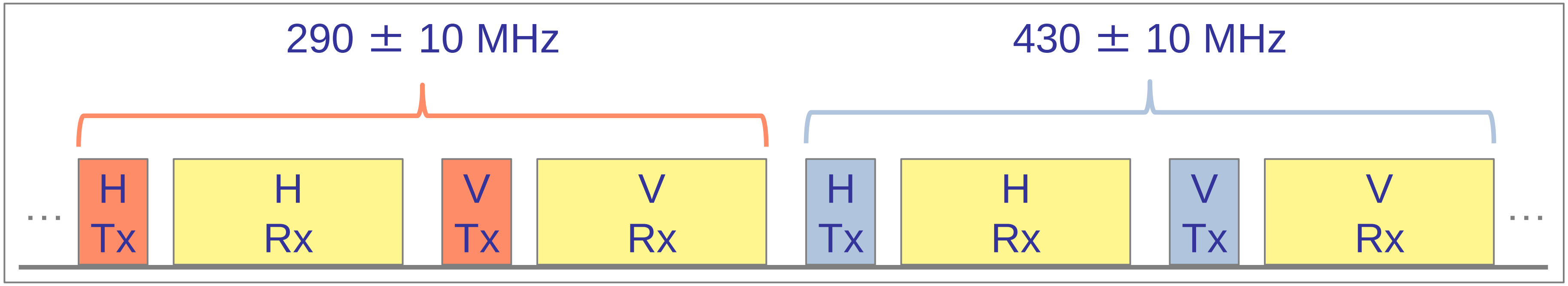
*Requires S/W, F/W or H/W Changes

6/7/2011 version 6.0

AirMOSS P-band SAR

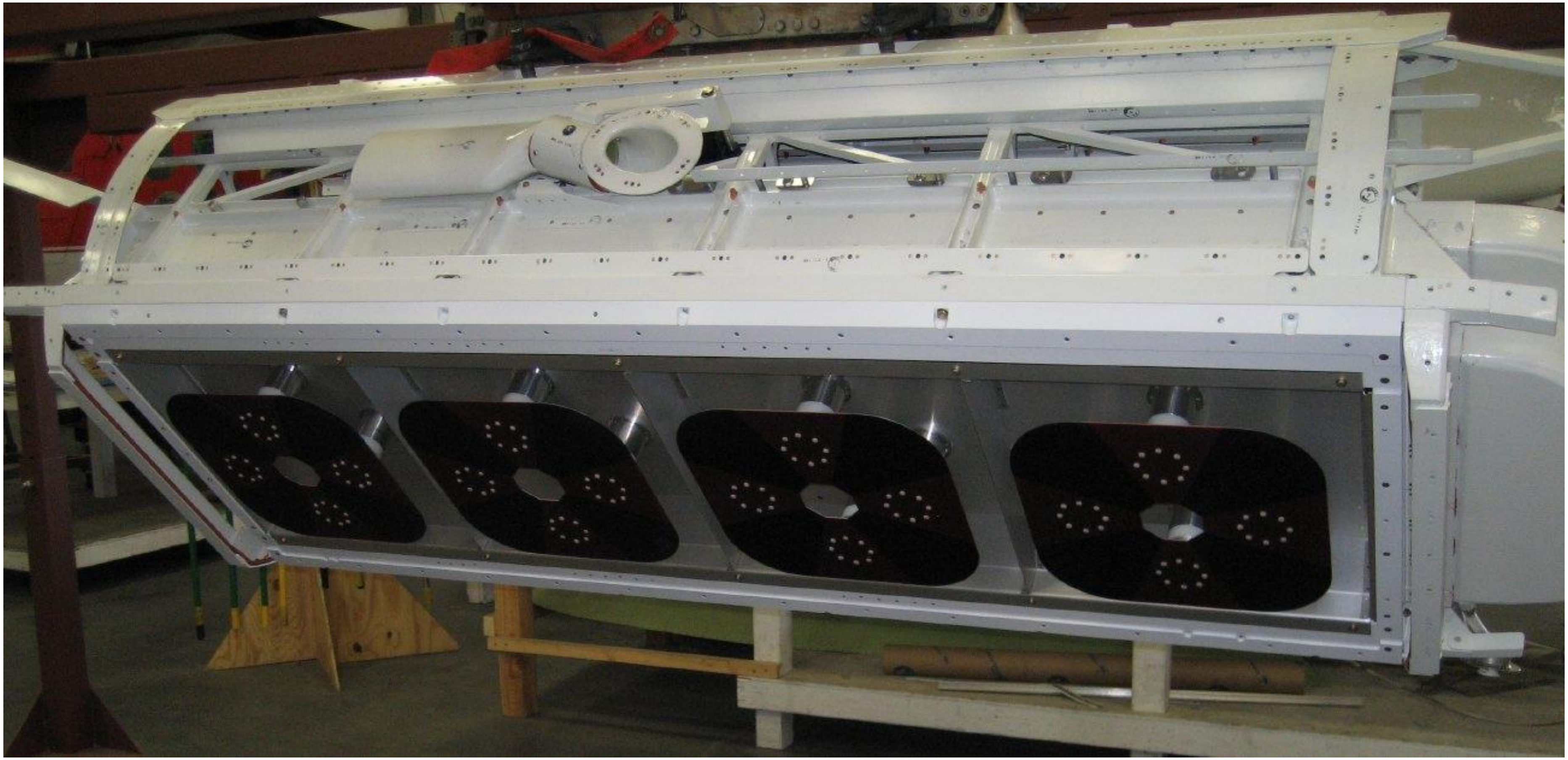
- Hardware is capable of 80 MHz maximum contiguous bandwidth within 280-440 MHz band – frequency *permission* is a limiting factor
  - Currently have regional permissions to transmit 420-440 MHz in AZ, CA, KS, ME, MA, NE, NH, NC, OR, TX, UT
- Direct Digital Synthesizer (DDS) which generates signal to mix L-band chirp down to P-band commandable to generate any center frequency between 280 and 440 MHz on a pulse by pulse basis.
- Can double Pulse Repetition Frequency (PRF) and concurrently collect polarimetric strip map SAR image data at multiple frequencies

For example:

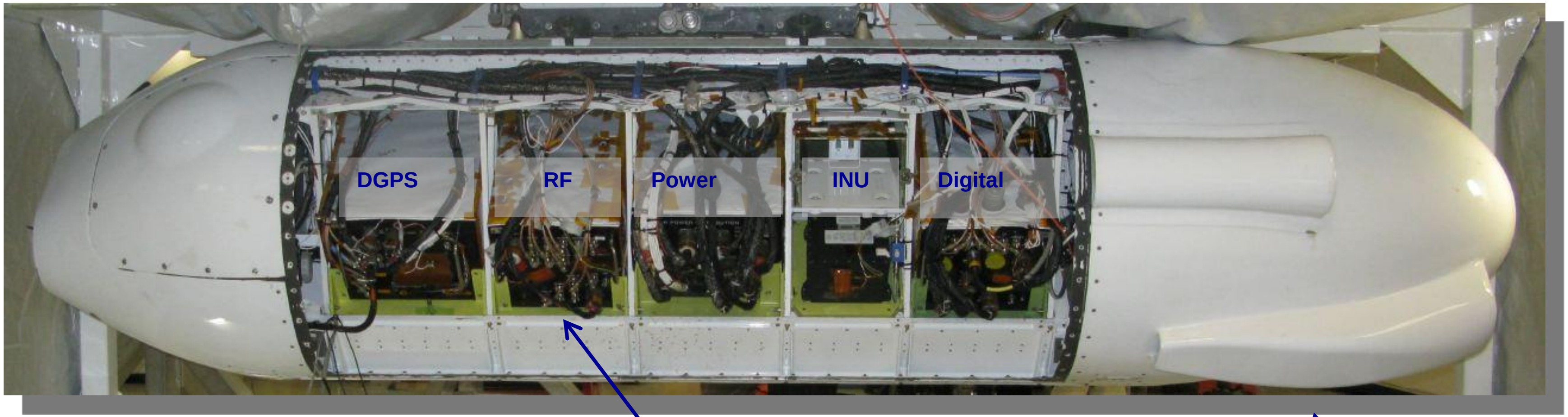


AirMOSS Heritage: GeoSAR Antenna

Passive GeoSAR antenna
(reduced in size by 3%)



Electronics Installed in Pod

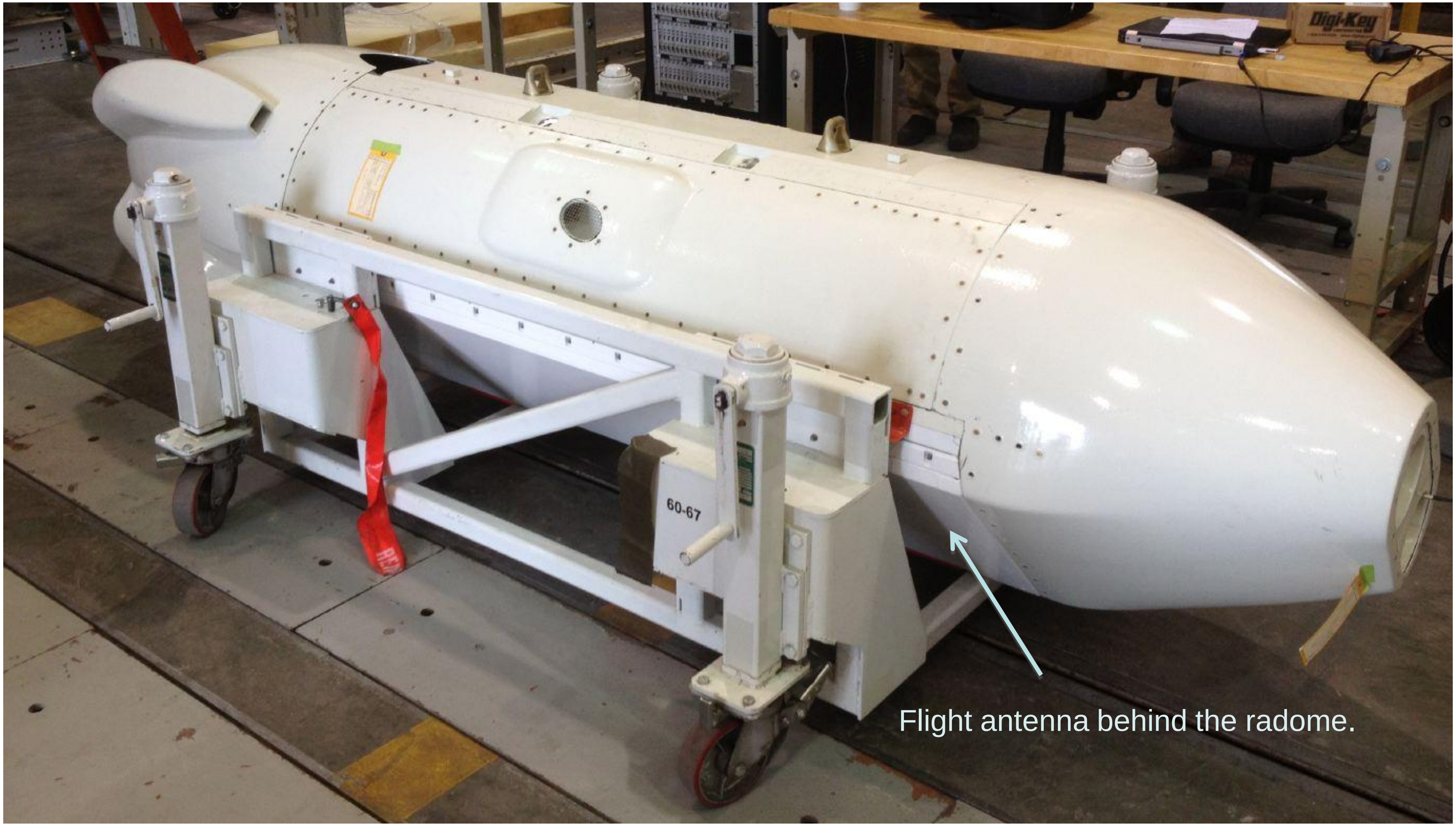


Add electronics for frequency up/down conversion between L-band and P-band

P-band high power amplifier in the nosecone

P-band antenna, not shown, on port side of pod

P-band Pod Prior To Temperature Performance Flight



P-band pod ready for inertia swing to measure the mass properties. Mass simulators are installed in the electronics bays and the nosecone whereas the flight antenna is installed behind the radome. First temperature performance flight was flown on Feb. 29.

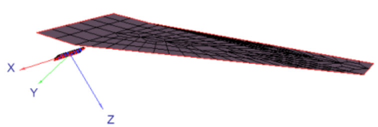
JSC G-III Aircraft

- JSC G-III aircraft has been modified to operate the UAVSAR and AirMOSS radars
- Aircraft arrived in Palmdale in mid-January and all support racks and cables in the cabin have been installed and checked out.
- P-band pod was installed to the aircraft and shakedown flights were performed late February

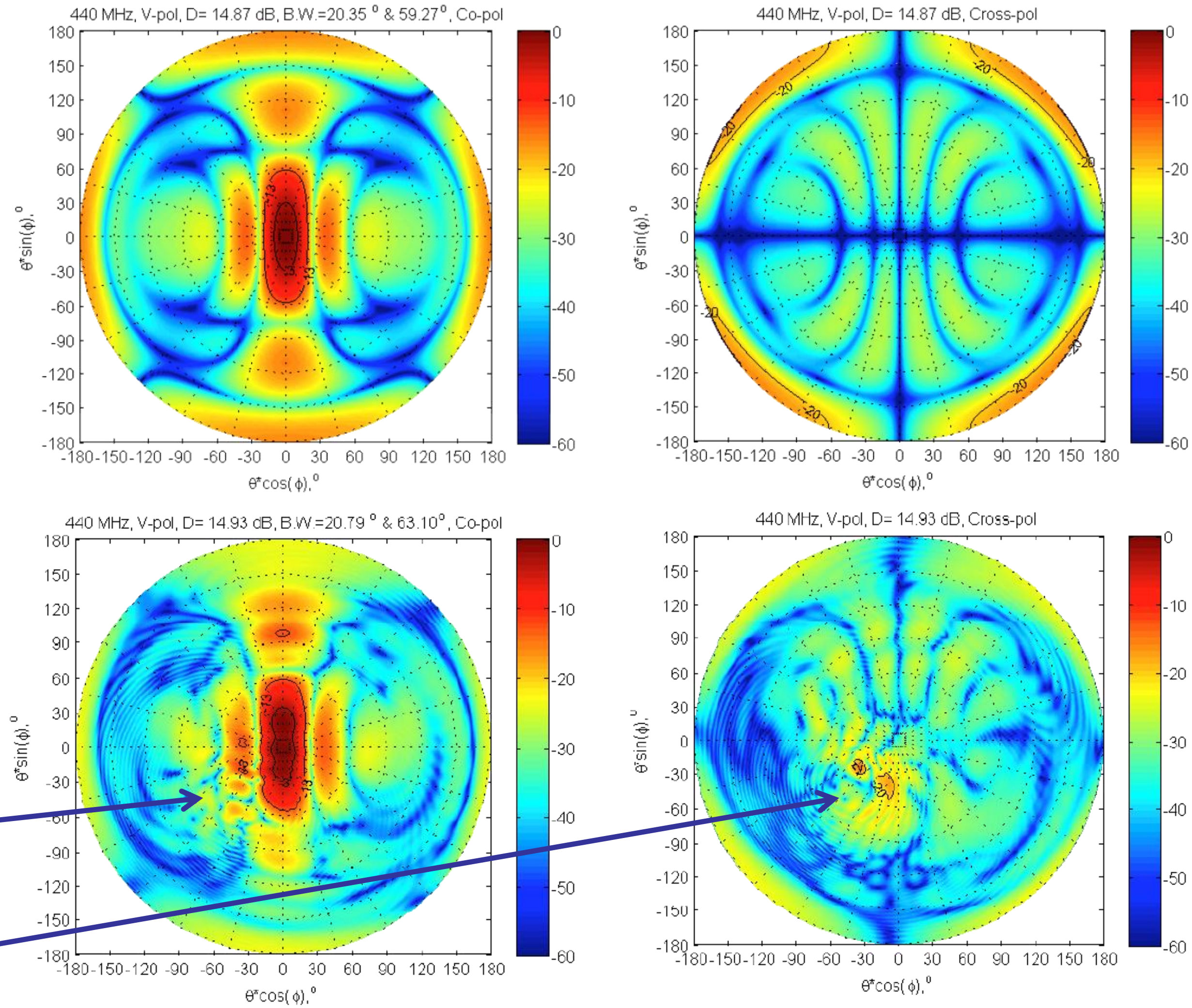
Wing Distorts Antenna Pattern

Antenna patterns were modeled with and without the wing using Ticra GRASP9.7.

The V pol 440 MHz pattern is shown.



Presence of the wing distorts the co-pol antenna pattern and adds significant gain in the cross-pol pattern.



Cross-pol Contamination

- Wing degrades the antenna's cross-pol isolation.
  - Effect amplified since backscatter cross section for cross-pol typically 15 dB weaker than co-pol.
- Cross-pol data (HV and VH polarizations) particularly valuable for vegetation signatures.
  - For AirMOSS project may need to rely on external vegetation data bases at sites.

$$P_{ret} \propto G_{Tx} G_{Rx} \sigma^0$$

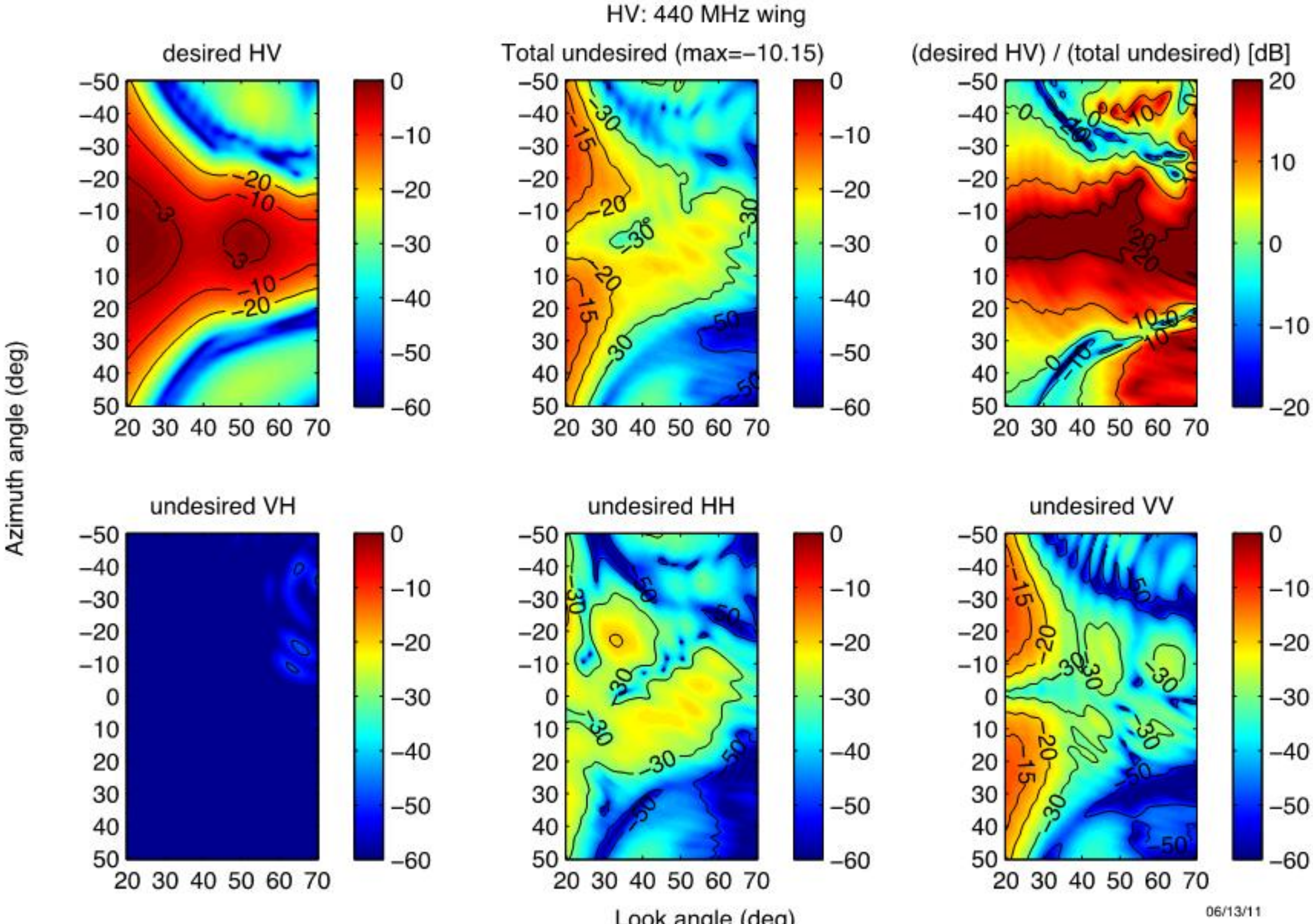
$$\begin{aligned}
P_{ret,HV} \propto\ & H_{co} V_{co} \sigma^0_{HV} && (desired\ HV) \\
& + H_{cx} V_{cx} \sigma^0_{VH} && (undesired\ VH) \\
& + H_{co} V_{cx} \sigma^0_{HH} && (undesired\ HH) \\
& + H_{cx} V_{co} \sigma^0_{VV} && (undesired\ VV)
\end{aligned}$$

These terms are non-negligible because of distortions caused by wing

H_{co}: H co-pol antenna gain

H_{cx}: H cx-pol antenna gain

Modeling of Cross-pol Contamination



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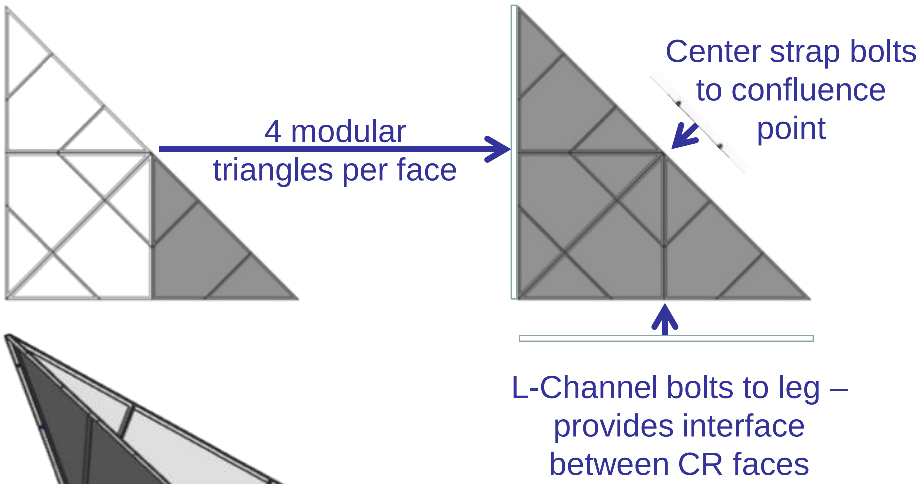
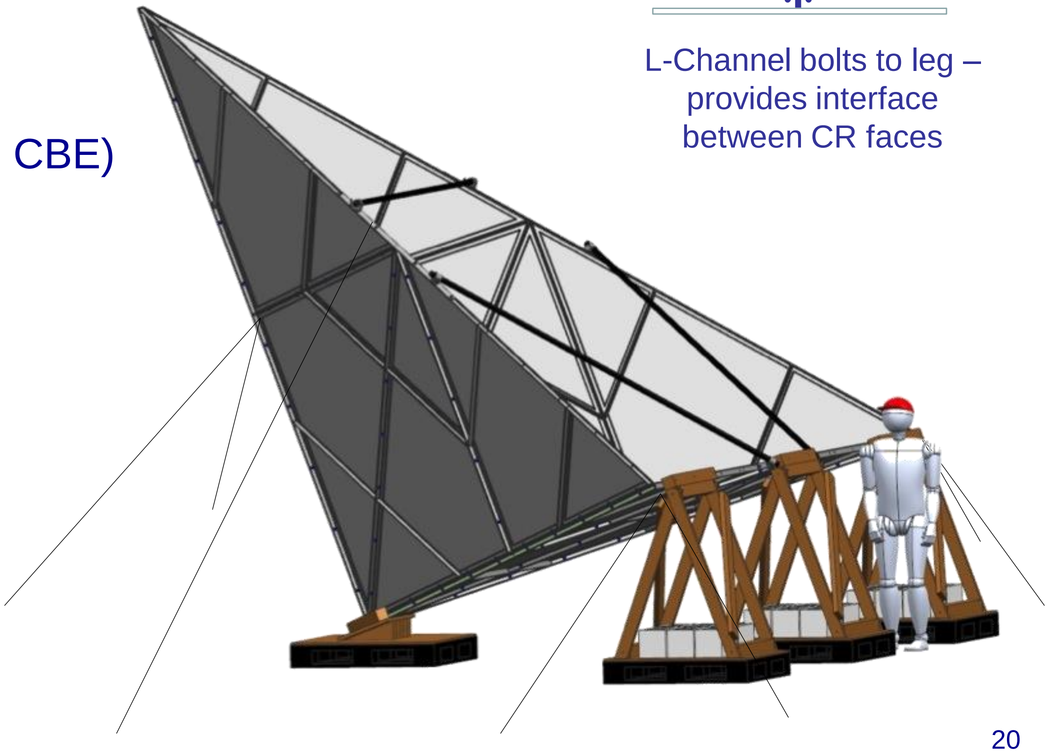
4.8 m L-band and P-band Corner Reflector

- Corner Reflector (CR) comprised of 12 identical modular triangles
- Size:
  - CR Leg: 4.80 m (15.8’)
  - CR Hypotenuse: 6.79 m (22.3’)
  - Modular triangle leg: 2.40 m (7.9’)
  - Modular triangle hyp: 3.39 m (11.1’)
- Weight:
  - CR: 238 kg (525 lbs CBE)
  - Modular triangle: 17 kg (37 lbs CBE)
- Stands:
  - 1 Vertex Balance Stand (VBS)
  - 3 Leading Edge Stands (LES)
- Retention:
  - Cinder blocks on LES
  - Stakes through stand bases
  - Guy ropes running to stakes

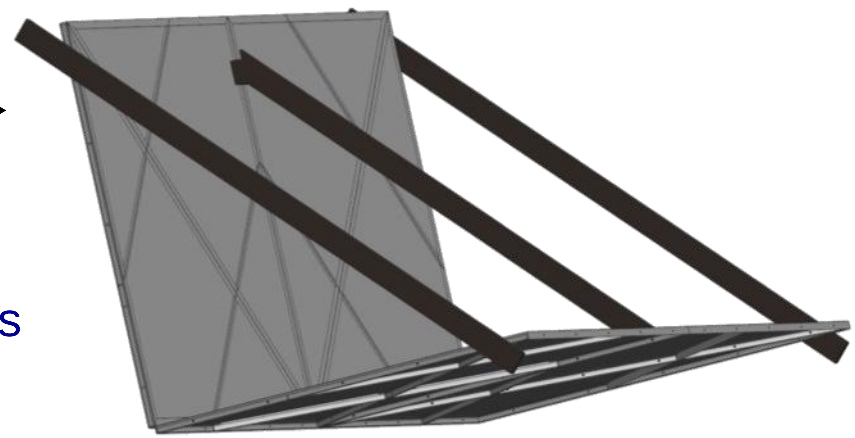




Modular Design – Reconfigurable

The modular design of the CR panels allow different size and shape reflectors to be constructed:

- Dihedral Corner Reflectors →
  - 2.4 m x 2.4 m 4 modular triangles
  - 2.4 m x 4.8 m 8 modular triangles
  - 4.8 m x 4.8 m 16 modular triangles



- Trihedral Corner Reflectors
  - ← 4.8 m 12 modular triangles (AirMOSS) [shown with 5' tall person for scale]
  - 3.4 m 6 modular triangles
  - 2.4 m 3 modular triangles (UAVSAR)

Questions

- A time lapse video of corner reflector assembly: